Appendix A. Biology of *Phytophthora ramorum*

GENERAL PLANT PATHOLOGY

Phytophthora ramorum is the causal agent of sudden oak death, ramorum blight, and ramorum die-back. It is known to occur in U.S. western coastal forests, in landscape plantings in Europe, and has been detected in nurseries in the United States. *Phytophthora ramorum* is one of a number of organisms (although not true fungi) that are collectively called "water molds." *Phytophthora* is translated to "Plant Destroyer" and most of the *Phytophthora* species are plant pathogens, many with extremely large host ranges.

IDENTITY

Name: *Phytophthora ramorum* Werres, de Cock, & In't Veld (2001)
Disease names: Sudden Oak Death, Phytophthora canker disease of oaks, Ramorum leaf blight, Ramorum twig blight or dieback

HOSTS

The host range for *Phytophthora ramorum* is broad and continues to expand. As of 1 December 2005, 38 plant species are designated as proven hosts and an additional 46 species as associated plants by USDA.

GEOGRAPHIC DISTRIBUTION

Europe:

- Belgium, Denmark, France, Germany, Ireland, Italy, Netherlands, Norway, Poland, Slovenia, Spain (Asturias, Galicia, Mallorca, Islas Baleares), Sweden, Switzerland and The United Kingdom.

North America:

- Canada
    - Infected nursery stock has been detected and destroyed in British Columbia.
- **United States**:
    - Infected nursery stock has been detected and destroyed in 21 states.
    - California
        - The disease is established in the environment and regulated in 14 counties (Alameda, Contra Costa, Humboldt, Lake, Marin, Mendocino, Monterey, Napa, San Francisco, San Mateo Santa Clara, Santa Cruz, Solano, and Sonoma).
    - Oregon
        - The disease is established in the environment and regulated in about 11 1/2 nine square miles in Curry County. Oregon is attempting to eradicate the pathogen from this zone.

There are no records of occurrence in Asia, Africa, the Caribbean, Central America, Mexico, Oceania or South America

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BIOLOGY and EPIDEMIOLOGY

Phytophthora ramorum has two mating types, A1 and A2. Initially, A1 isolates were found in Europe and A2 isolates in the United States. The two mating types are genetically different and are thought to be distinct populations. In 2003, the A1 mating type was found in North America and the A2 mating type in Europe. This is a cause for concern. The A1 is more aggressive than the A2 mating type and offspring of A1 and A2 would have greater genetic variation than currently exists and would have higher probability of producing more aggressive offspring. Morphological and molecular comparisons of U.S. and EU isolates indicate that the two mating types are the same species.

Hosts of *P. ramorum* usually fall into one of three categories, canker hosts, leaf hosts, twig hosts. Infections in leaf and twig hosts are rarely fatal, but act as a reservoir for the pathogen. Sources of inoculum are the reproductive structure that are produced on several foliar and dieback hosts. Canker hosts exhibit infections on basal stems and often die. Spore production has not been observed on canker surfaces of these hosts, although exudates have tested positive with PCR. However, if the inner bark (cambium) is exposed and free water is present, the pathogen can produce spores on these exposed surfaces.

Pathways for long-distance dispersal includes movement of infected plant material (wood, green material products, and nursery stock), soil, water (rain, runoff, streams, rivers and irrigation water), animals, and aerial dissemination during major weather events. It is postulated that long distance dispersal through aerial dissemination is responsible for the spread of the A2 mating type in the U.S.

DETECTION AND IDENTIFICATION

Symptoms

Three different syndromes are attributed to *P. ramorum*: stem or bole canker, leaf blight, and twig blight or dieback. Hosts which are prominent in the nursery trade include *Rhododendron*, *Camellia*, *Viburnum*, *Pieris*, *Kalmia,* and *Syringa*. Symptoms on *Rhododendron* closely resemble those caused by other *Phytophthora* species or those caused by environmental stress (drought, *etc*.), making inspection for the disease more complicated and detection more challenging. With *Lithocarpus* species, drooping or wilting of new growth occurs before other symptoms appear. Cankers typically occur in the lower three meters and are restricted to above the soil line. Occasionally cankers have been found 20 meters above ground. Cankers can eventually kill the tree by attacking the phloem and girdling the tree. Bleeding symptoms of the canker are easier to detect during dry weather and become more difficult to detect during the rainy season.

Laboratory Isolation, Detection and Characterization

Infection with *P. ramorum* can be made through isolation of the organism through culturing, and PCR (both nested and real time methods). ELISA can be used as a screening test for the presence of Phytophthora species in a sample. ELISA is not species specific and cannot be used to diagnosis infection with *P. ramorum*. Culture methods and PCR can detect the organism in plant tissue, soil, potting media, and water. Recovery rates during culturing may vary with season and host and are facilitated by the use of the selective medium, PARP. PCR methods are very sensitive and seem less influenced by these factors.

Affected Plant Parts and Symptoms:

- Growing points:
  - lesions; dead heart; discoloration; mycelium present; wilt.
- Leaves:
  - lesions; abnormal colors; abnormal leaf fall; wilting; fungal growth; yellowed or dead.
- Stems:
  - internal discoloration; external discoloration; canker; abnormal exudates; dieback.
- Whole plant:
  - dieback; discoloration, death;

Means of Movement and Dispersal

The scattered pattern of sites where *P. ramorum* has become established suggests that it has a mechanism to spread over large areas. Initial survey results in California and Oregon indicate the presence of *P. ramorum* in streams and rivers adjacent to and far from known infested areas. Inoculum has been seasonally detected from soil in hiking trails and from soil on hikers' boots.

Economic Impact

California's oak woodlands and timberlands have approximate total lumber values of $275 million and $500 million, respectively. Oak products exported from California from 1996-2000 averaged almost $50 million per year. There is potential economic threat to eastern U.S. oaks. Two oak species native to eastern U.S., *Quercus rubra* and *Q. falcata,* were found naturally infected in Europe. Susceptibility of other eastern U.S. tree species (*Q. alba*, *Q. laurifolia, Q. nigra, Q. pagoda*, *Q. phellos, Q. prinus*, *Q. virginiana*, *Acer saccharum,* and *Juglans nigra*) has been experimentally demonstrated. This represents a potential economic threat to commercial timber production in the U.S. exceeding $30 billion. The export value of red oak logs and lumber was over $300 million dollars in 2002.

The U.S. nursery industry is also at risk. Nursery crops include woody perennial plants, such as ornamental trees, shrubs, and vines, which are primarily used for landscaping. In 2003, the U.S. domestic production of nursery crops was valued about $9.2 billion, imports for these crops total $483 million and exports were valued at $210 million.

Tourism may also be affected. Visitors to parks and forests could be impacted because access to selected areas may be restricted during certain seasons to prevent movement of the pathogen, or to protect visitors from falling limbs of trees affected by this disease.

The presence of *P. ramorum* has resulted in restrictions in foreign and domestic trade. Canada, Korea, Australia, New Zealand, and the European Union have placed restrictions on the movement of affected plants and plant parts from the U.S. In addition, the U.S. has placed restrictions on the movement of propagative material from the European Union.

Environmental Impact

Forest pathogens cause the loss of approximately 9%, or $7 billion, of forest products each year. In addition to the direct costs of prevention, eradication or suppression of this pathogen, economic costs also include indirect ecological consequences. Economic costs include perturbations of hydrological cycles (*e.g.*, flood control and water supply), waste assimilation, nutrient recycling, crop pollination, and conservation and regeneration of soils. These costs may affect both current-use value and future-use values.

Quercus species are the most important and widespread hardwood trees in the North Temperate Zone. These woodlands yield important benefits such as water and watershed protection, wildlife food, and habitat, recreation, and wood products. Woodlands are known for their scenic beauty, contribution to tourism and high property values and are valued for shelter and food for wildlife. The loss of keystone *Quercus* species in these forests would be detrimental to forest health. In addition, the effects on rare and endangered plant species in these regions are unknown. *Phytophthora ramorum* may cause significant direct environmental effects, such as extensive ecological disruption and large-scale reduction of biodiversity. This pathogen has already caused extensive environmental damage through the death of thousands of *Quercus* and *Lithocarpus*. The effect of these losses on animal populations and the resulting increased risk of forest fires are currently being studied. Existing data show changes in bird populations but the total impact is unknown.

A number of plant species on the U.S. Fish and Wildlife Service's threatened and endangered species list are in genera contained on the APHIS List of Hosts and Associated Plants (HAPS). These are *Rhododendron chapmanii , Quercus hinckleyi, Arctostaphylos confertiflora*, *A. glandulosa ssp. crassifolia*, *A. hookeri* var. *ravenii*, *A. morroensis*, *A. myrtifolia*, and *A. pallida*.

MITIGATION MEASURES

Traditional regulatory mitigation programs for plant pathogens focus on exclusion, containment, suppression, and eradication.

Exclusion – Exclusion of *P. ramorum* from natural areas will require large geographic barriers. The reproductive structures are locally dispersed in rain events, and are postulated to move long distances by significant weather events.

Containment – Under current Federal domestic regulations, nurseries in quarantined areas must be inspected, sampled and tested annually for symptoms of *P. ramorum*. Containment efforts for *P. ramorum* in nursery stock have focused on national surveys and the development of best management practices for nurseries. Containment measures used for other *Phytophthora* species include sanitation, disinfectants, fungicides, fumigants, methods of water treatment and distribution, and type and form of bed beneath the growing containers. Eradication efforts are initiated if the pathogen is detected during any inspection process.

Suppression – Suppression efforts for *P. ramorum* in forests in the quarantined counties of California have focused on educational outreach, seasonal closure of trails, and facilities to remove soil from shoes, bicycle tires, vehicles, and equipment. Eradication, not suppression,

is undertaken when *P. ramorum* is found in nurseries.

Eradication –Removing and destroying plant material and related articles, disinfection, and follow-up surveys are the major tools for eradicating *P. ramorum* in nurseries. The only current effort to eradicate *P. ramorum* from a forest setting through removal and destruction of infected and at-risk plant material is underway in Curry County, Oregon.

Sanitation – Sanitation, during and after propagation, is necessary to maintain pathogen-free material. To control a polycyclic foliar pathogen, such as *P. ramorum*, in the field, sanitation needs to be 99.9% effective. Sanitation practices should include removing and testing of symptomatic stock, sterilizing potting media, and disinfecting tools, benches, workers' clothing and equipment. All symptomatic material or diseased plants should be disposed in a sanitary landfill or treated. Contaminated irrigation and recycled water disperses *Phytophthora* propagules, directly, by delivering contaminated water, or indirectly by splashing inoculum from plant and ground surfaces to other plants. Methods to disinfest water include chlorine, filters and ozonation. Water treatment should be coupled with testing before and after treatment. Chemical control includes disinfectants for equipment and fungicides for the pathogen. Fungicides, however, are fungistatic for *P. ramorum*; they do not kill the organism but suppress growth and development of disease symptoms.